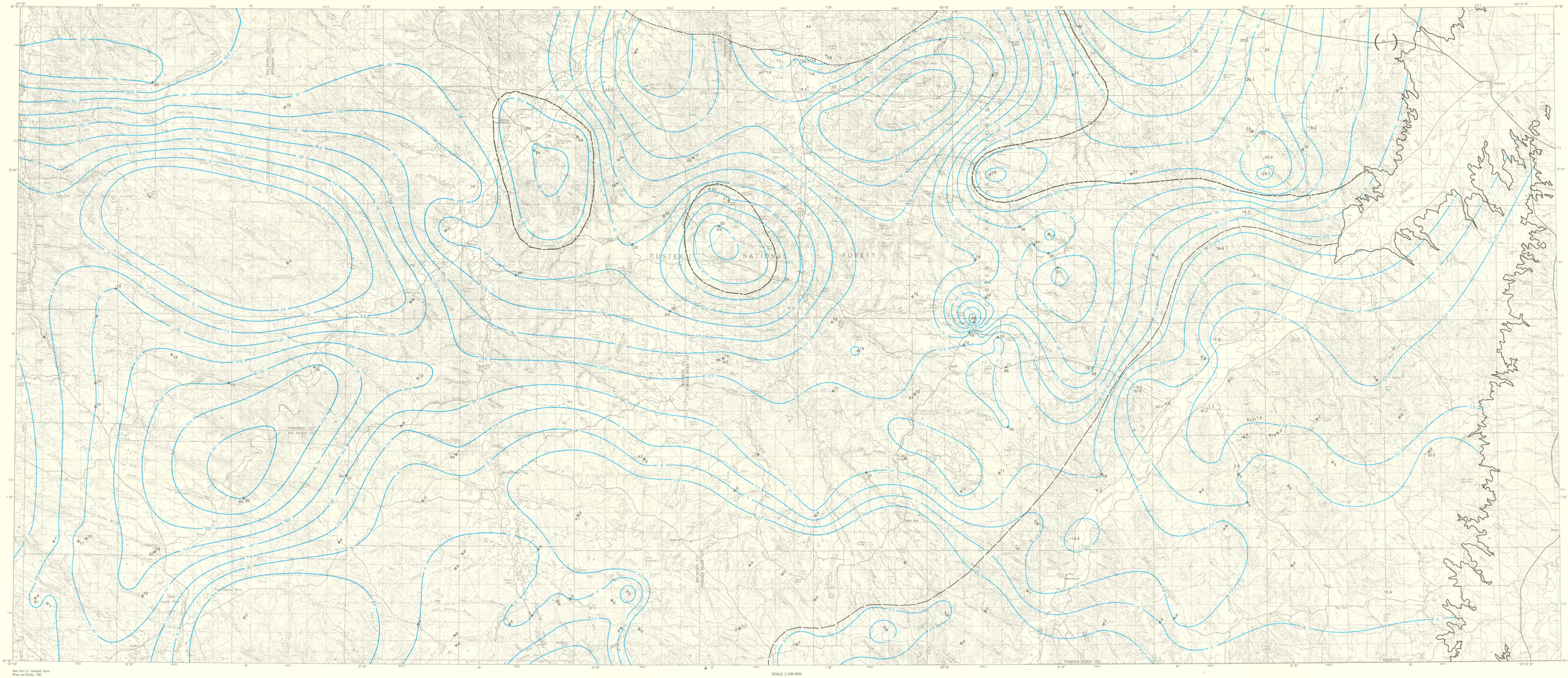

ISOPACH MAP OF THE FLOWERS-GOODALE COAL BED

EXPLANATION FOR ISOPACH MAP OF FLOWERS-GOODALE COAL BED

[Note: Coal thicknesses will change more abruptly at split and merge lines than the gradual changes shown on map]

Edge of coal bed—Inferred contact where base of Flowers-Goodale coal resource unit intersects land surface

Isopach—Showing thickness (in feet) of Flowers-Goodale coal bed. Contour interval 2.5 ft. 2.5-ft isopach is subsurface boundary for coal resource classification

Flowers-Goodale split line—Inferred boundary south and east of which Flowers-Goodale coal resource unit is split into two separate beds: the main bed and the upper split

Knobloch split line—Inferred boundary north of which Flowers-Goodale coal resource unit merges with overlying Knobloch coal resource unit (Culbertson and Sapenstone, 1987b)

Merge line—Inferred boundary within which underlying Witham coal bed merges with Flowers-Goodale coal bed

Drill-hole locality and thickness (in feet) of the Flowers-Goodale coal bed

•19 Coal exploratory drill hole

25 Oil and gas test hole

A7 Map No. of drill hole used on correlation diagrams

( ) Cut out—Shown at data point where sandstone channel is present at horizon of Flowers-Goodale coal bed

INTRODUCTION

The Flowers-Goodale coal resource unit occurs in the lower part of the Paleocene Tongue River Member of the Fort Union Formation. It is defined here to include two beds: the Flowers-Goodale coal bed and its upper split. Our study area comprises all of the Birney 30′ × 60′ quadrangle and the west half of the Broadus 30′ × 60′ quadrangle, in southeastern Montana and northernmost Wyoming in the northern part of the Powder River Basin. This report shows trends of thickening, thinning, and splitting of the Flowers-Goodale coal resource unit in the study area and the stratigraphic relationship of the coal to other coal beds in the Fort Union Formation; areas of coal resources are also shown. This work is an outgrowth of the Coal Folio Program for the Broadus 30′ × 60′ quadrangle. On the basis of the sparse chemical data (three samples) available in NCPDS (National Coal Resources Data System) for the Flowers-Goodale coal resource unit from just north of the Birney quadrangle, the coal in this unit is subbituminous C and the sulfur and ash contents are low, with mean values of 0.47 and 8.4 percent, respectively (Affolter and others, 1979).

By correlating the Fort Union Formation coal beds, several authors have reconstructed the stratigraphic framework of coal-bearing rocks for the study area and for much of the Powder River Basin (see, for example, Kent and others, 1980; Pierce and Molnia, 1985; Hardie and Van Gosen, 1986; Culbertson, 1987; Culbertson and others, 1979; McLellan and Biewick, 1988; Pierce and others, in press; McLellan and others, in press). In the Birney and Broadus quadrangles, an interlocking network of closely spaced correlation diagrams illustrates the stratigraphic framework and reveals the extent of the coal beds in the Fort Union Formation (Culbertson, 1987; McLellan and Biewick, 1988).

METHODOLOGY

The data used to generate the maps were retrieved from NCRDS; data in the Birney quadrangle (west of long 106° W.) are according to Culbertson's (1987) nomenclature. The correlation diagrams were assembled using the program STRATS (Boger, 1986), and the isopach maps and projections were generated using the Surface Mapping System (Golden Software, Dynamic Graphics, Inc., on a Prime 9650 minicomputer).

Subsurface data were interpreted from geophysical logs of drill holes in and adjacent to the study area. The isopach maps show the locations of the 174 drill holes used in constructing these maps. About 25 percent of the drill holes are coal exploration holes drilled by the Montana Bureau of Mines and Geology, the U.S. Geological Survey, the U.S. Bureau of Reclamation, and private individuals and companies. Most of these holes are located in the valleys and tributaries of Powder River and Otter Creek, where the Flowers-Goodale coal resource unit is at shallow depth. These holes provide the most reliable data on coal beds. The remaining drill holes used in this report are oil and gas test holes that have adequate geophysical logs available for interpretation of the thickness and depth of the Flowers-Goodale coal resource unit; the logs of oil and gas holes provide almost the only available information west of long 106°15′ W. and under the high divides between and adjacent to Powder River and Otter Creek. Preference was given to the use of 2-in-scale logs of gamma-ray and formation-density logs. Gamma-ray and formation-density logs are the most common logs run in holes drilled for coal and are the most sensitive to density than the adjacent rocks. Coal beds have a high resistivity curve on electrical-resistivity logs, but so do some sandstone and limestone beds. Consequently, the resistivity log is only used to determine coal thickness where the log can be correlated with a suite of logs from a nearby drill hole that includes gamma ray or formation density (Wood and others, 1983, p. 66–68). Gamma-ray logs are available for 55 percent of the oil and gas holes and 76 percent of the coal exploration holes. Formation-density logs are available for 73 percent of the coal exploration holes. Rocks in two of the coal exploration holes cored before well logs could be measured; therefore, only lithologic logs from cuttings are available for the Flowers-Goodale coal resource unit in holes USGS BCR 80-A1 and 80-E7 (McLellan and Biewick, 1988).

Surface data were taken from published and unpublished maps resulting from coal mapping programs of the U.S. Geological Survey (McLellan and Biewick, 1988). Coal thicknesses based on measurements of surface exposures are rare, because exposures are poor and because weathered coal and accurate measurements may be unreliable as a result of possible decrease in thickness on the coal outcrop due to slow oxidation during weathering. When subbituminous coal is exposed to air, it "slakes," or breaks down into small fragments that are readily subject to oxidation (Robinson and Culbertson, 1984). Furthermore, slumping of strata overlying the top of the coal bed may result in the observer mistaking the slumped top of the coal bed for the true top.

In this report, elevations of the base of the coal taken from outcrops were used along with those taken from geophysical logs to generate the structure of the coal bed. The coal bed is used as a stratigraphic marker to show underlying the structure at the base of the coal bed, the edge-of-coal-bed line is located, indicating where the base of the coal intersects the surface.

In many places along much of its former outcrop, the Flowers-Goodale coal has burned; the heat thus generated has baked and fused the overlying rocks into a resistant red rock called clinker. The location of the edge-of-coal-bed line, which represents the outcrop, is subject to local error because of the difficulty in locating the edge of clinker on the surface owing to: (1) the coal bed possibly having burned for a short distance without altering the appearance of the surface rocks and (2) the upper part of a thick bed of coal having burned only locally, turning the overlying rock into clinker, and thereby concealing the presence of the lower unburned coal (Culbertson and Sapenstone, 1987b). This is a minor problem along much of the outcrop because of the thinness of the coal bed. Although the amount of coal burned is unknown, it is probably negligible (Robinson and Culbertson, 1984) and not important for resource consideration.

THE COAL-BEARING SECTION

The Paleocene Fort Union Formation consists of, in ascending order, the Tullock Member, the Lebo Shale Member, and the Tongue River Member. The Tullock Member, which contains only local stringers of coal, consists mostly of thin-bedded sandstone and siltstone. The Lebo Shale Member consists largely of mudstone and shale, with a few thin beds of sandstone. The Tongue River Member consists of interbedded sandstone, siltstone, shale, coal, and a few thin lenses of limestone. The coal-bearing Wasatch Formation of Eocene age overlies the Fort Union Formation in the high drainage divides in the south and west margins of the Birney quadrangle; however, the principal coal-bearing sequence in the Fort Union Formation in the study area is the one shown in the accompanying diagrams occur in the Tongue River Member.

The Flowers-Goodale coal resource unit includes the Roberts coal bed of Culbertson (1987); the authors believe these coals to be equivalent. As so defined, the Flowers-Goodale coal resource unit not only underlies the Birney quadrangle and the west half of the Broadus quadrangle, but it also extends north into the Lame Deer and Powderville quadrangles, west into the Lodge Grass quadrangle, and south into the Sheridan quadrangle.

Where a parting (a layer or stratum of noncoal material) is a coal bed that does not exceed the thickness of the coal in either the directly underlying or overlying benches; Wood and others, 1983) is present the thicknesses of the underlying and overlying coal beds are added together and treated as one coal bed. Where a layer of noncoal material exceeds the thickness of either the underlying or overlying coal benches, the coal bed is considered to have split into two coal beds. Using these criteria, the Flowers-Goodale coal bed consists of (1) the Flowers-Goodale bed where it is a single bed, (2) the main bed where the upper split is separated from the main bed by a thicker noncoal bed, and (3) the upper split where it is separated from the main bed. In places where these beds merge or where the Witham bed is separated from the overlying Flowers-Goodale bed by a parting.

The variation in thickness of the coal beds is clearly displayed in the perspective projections. Exaggeration of the coal thickness (height) in relation to X and Y axes (horizontal distance) is necessary to provide sufficient relief to show thickness variations clearly.

The Flowers-Goodale coal bed is thickest (greater than 30 ft) where it is combined with the Witham coal bed in the northeastern part of the study area and in two areas in the north-central part of the study area (delineated by merge line on isopach map of Flowers-Goodale coal bed). The upper split is confined to the east-central and southeastern parts of the study area, where it ranges in thickness from 1.9 to 8.0 ft; elsewhere, the upper split merges with the main bed. In the northern part of the Birney quadrangle, the Flowers-Goodale coal bed merges with the Nance, Knobloch, and Calvert coal beds (Hansen, 1986; Culbertson and Sapenstone, 1987a, p. 501–515; Culbertson and Sapenstone, 1987b). Southeastward the Flowers-Goodale coal bed thins and appears to pinch out, suggesting that the south edge of the Broadus quadrangle may approximate the former southern extent of the peat swamp.

The 2.5-ft isopach marks the subsurface boundary of the Flowers-Goodale coal resource unit for resource calculation purposes; 2.5 ft is the minimum thickness of subbituminous coal that is considered to be a coal resource by the U.S. Geological Survey (Wood and others, 1983). Areas of zero coal thickness on the isopach maps and perspective projections show where the coal has pinched out, except in the northeastern part of the study area (T. 4 S., R. 50 E.) where a 50-ft-thick sandstone present at the Flowers-Goodale coal bed horizon suggests that the coal was cut out (shown as a broken line on the Flowers-Goodale coal bed isopach map). In the northwestern part of the Birney quadrangle (sec. 36, T. 4 S., R. 39 E.), directly above the 25-ft-thick coal, there appears to be a thick sandstone that can be correlated further south to the two localities in sec. 36, T. 5 S., R. 39 E., and sec. 21, T. 6 S., R. 41 E. where coal is not present. It appears that the coal pinches out between the drill hole in sec. 36 and the outcrop to the south and west, probably due to lack of data where only a resistivity log is available. In T. 7 S., R. 47 E., the 29-ft thickness of the coal bed may be questionable because only a resistivity log was available and nearby coal thicknesses are 10–15 ft thinner. The coal bed appears to be 29 ft thick on the resistivity log, but the geophysical signature may include both the coal and an overlying sandstone bed.

DEPOSITIONAL SETTING OF OVERBURDEN

The strata overlying the Flowers-Goodale coal resource unit consist of sandstone, siltstone, shale, coal, carbonaceous shale, limestone, and ironstone. Lithofacies and depositional environments for the stratigraphic interval above the Sawyer coal bed have been described by Flores (1983, 1983) from studies of continuous exposures on moderately high cliffs along Tongue River, Powder River, and Otter Creek. On the basis of the spatial arrangement of the lithofacies, Flores (1983) recognized four depositional environments: (1) channel-fill lithofacies and a lacustrine-floodplain lithofacies, (2) a subordinate backswamp lithofacies, which consists of coal and carbonaceous shale, occurs within both of these lithofacies. The meander belt lithofacies is characterized by high concentrations of channel sandstones, whereas the lacustrine-floodplain lithofacies consists of finer grained sandstone, siltstone, and shale, as well as abundant limestone and ironstone (Flores, 1983). The rocks above the Anderson coal bed are described as fluvial lake-dominated facies, and the stratigraphic interval from just below the Cache coal zone to the Anderson coal bed is described as fluvial-dominated facies (Flores, 1981).

CONCLUSIONS

Near the Montana-Wyoming border all coal beds below the Cache coal zone in the Broadus quadrangle die out and are not correlative with coal beds of approximately the same age in the Recluse Gillette, Wyo., area (McLellan and others, in press, cross section C-C'). Much of the central part of the basin may have remained submerged during the early Paleocene (McLellan and others, in press). Across southern Montana, the lower part of the Tongue River Member grades into and intertongues westward with shale of the Lebo Shale Member (McLellan, in press).

A more detailed analysis of sandstone intervals between the Flowers-Goodale coal resource unit and the directly overlying and underlying coal beds in the Tongue River Member would result in improved understanding of the depositional environments in this part of the coal-bearing section. Isopach maps of the Knobloch, Wall, and Canyon coal beds in the Birney quadrangle can be found in Culbertson and Sapenstone (1987a, b) and Robinson and Culbertson (1984). Delineation of these coal beds in the Broadus quadrangle and other coal beds in the Tongue River Member in both the Birney and Broadus quadrangles would show where coal deposition shifted through time.

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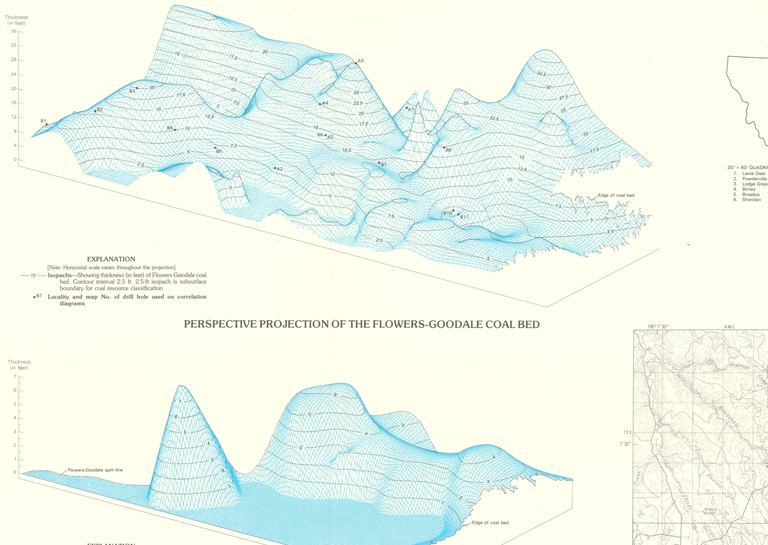
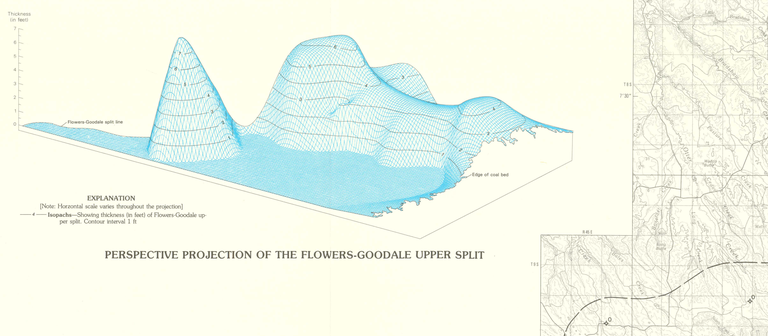


PERSPECTIVE PROJECTION OF THE FLOWERS-GOODALE COAL BED

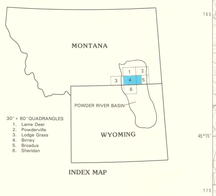


EXPLANATION

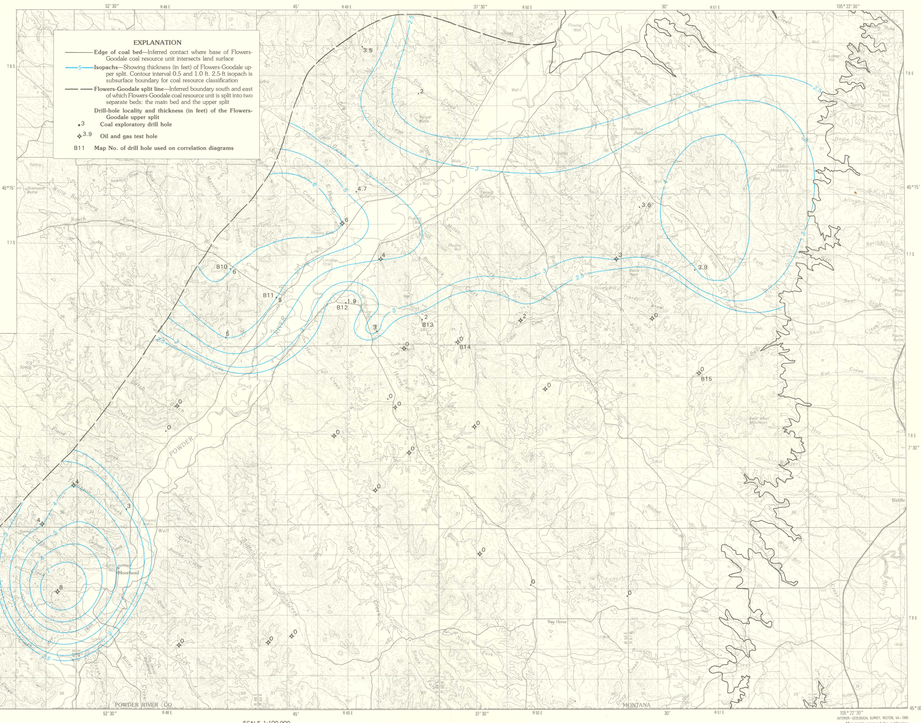
[Note: Horizontal scale varies throughout the projection]

Isopachs—Showing thickness (in feet) of Flowers-Goodale upper split. Contour interval 1 ft

PERSPECTIVE PROJECTION OF THE FLOWERS-GOODALE UPPER SPLIT



INDEX MAP



ISOPACH MAP OF THE FLOWERS-GOODALE UPPER SPLIT

ISOPACH MAPS, PERSPECTIVE PROJECTIONS, AND CORRELATION DIAGRAMS OF THE PALEOCENE FLOWERS-GOODALE COAL RESOURCE UNIT IN THE NORTHERN POWDER RIVER BASIN, BIRNEY AND BROADUS 30′ × 60′ QUADRANGLES, MONTANA-WYOMING

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